STRUCTURE AND TRANSFORMATION OF MATTER

A basic understanding of matter is essential to the conceptual development of other big ideas in science. In the elementary years of conceptual development, students will be studying properties of matter and physical changes of matter at the macro level through direct observations, forming the foundation for subsequent learning. During the middle years, physical and chemical changes in matter are observed, and students begin to relate these changes to the smaller constituents of matter—namely, atoms and molecules. By high school, students will be dealing with evidence from both direct and indirect observations (microscopic level and smaller) to consider theories related to change and conservation of matter. The use of models (and an understanding of their scales and limitations) is an effective means of learning about the structure of matter. Looking for patterns in properties is also critical to comparing and explaining differences in matter.

High School

Physical Science

SC-HS-1.1.1 Use data to distinguish patterns and make generalizations and inferences about the periodic table.

The periodic table is a consequence of the repeating pattern of outermost electrons.

SC-HS-1.1.2 The atom's nucleus is composed of protons and neutrons that are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

SC-HS-1.1.3 Solids, liquids, and gases differ in the distances between molecules or atoms and therefore the energy that binds them together. In solids, the structure is nearly rigid; in liquids, molecules or atoms move around each other but do not move apart; and in gases, molecules or atoms move almost independently of each other and are relatively far apart.

SC-HS-1.1.4 In conducting materials, electrons flow easily; whereas, in insulating materials, they can hardly flow at all. Semiconducting materials have intermediate behavior. At low temperatures, some materials become superconductors and offer no resistance to the flow of electrons.

SC-HS-1.1.5 Use patterns to make generalizations about the physical properties of compounds. Analyze the process of molecular interactions. Make predictions or inferences about interactions from data/information about the structure of molecules. The physical properties of compounds reflect the nature of the interactions among molecules. These interactions are determined by the structure of the molecule including the constituent atoms.
SC-HS-1.1.6 Analyze chemical reaction rate data. Design investigations/experiments to test the effect of variables such as concentration, temperature, and catalysts on reaction rates. Justify conclusions based on evidence/data from chemical reactions. Rates of chemical reactions vary. Reaction rates depend on concentration, temperature, and properties of reactants. Catalysts speed up chemical reactions.
SC-HS-1.1.7 Construct diagrams to illustrate ionic and covalent bonding. Use patterns to make generalizations and predictions of compound formation and bond type. Bonds between atoms are created when outer electrons are paired by being transferred (ionic) or shared (covalent). A compound is formed when two or more kinds of atoms bind together chemically.

MOTION AND FORCES

Whether observing airplanes, baseballs, planets, or people, the motion of all bodies is governed by the same basic rules. In the elementary years of conceptual development, students need multiple opportunities to experience, observe, and describe (in words and pictures) motion, including factors (i.e., pushing and pulling) that affect motion. At the middle level, qualitative descriptions of the relationship between forces and motion will provide the foundation for quantitative applications of Newton's Laws. These ideas are more fully developed at the high school level along with the use of models to support evidence of motion in abstract or invisible phenomena such as electromagnetism.

High School

Physical Science

SC-HS-1.2.1 Accurately represent motion visually, graphically and numerically. Analyze and select appropriate graphical representations for motion. Use evidence/data to support conclusions about the motion of objects. Propose explanations for real life motion phenomena.

Objects change their motion only when a net force is applied. Newton's Laws of motion are used to describe the effects of forces on the motion of objects. Conservation of mechanical energy and conservation of momentum may also be used to predict motion.

SC-HS-1.2.2 Formulate questions, and design investigations of electromagnetism, Analyze and appropriately represent electromagnetic data. Use evidence/data to propose solutions to real life problems involving electromagnetism.

Electricity and magnetism are two aspects of a single electromagnetic force. Moving electric charges produce magnetic forces or "fields", and moving magnets produce electric forces or "fields". This idea underlies the operation of electric motors and generators.

SC-HS-1.2.3 The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel.

THE EARTH AND THE UNIVERSE

The Earth system is in a constant state of change. These changes affect life on earth in many ways. Development of conceptual understandings about processes that shape the Earth begin at the elementary level with understanding *what* Earth materials are and that change occurs. At the middle level, students investigate *how* these changes occur. Finally, at the high school level, most of the emphasis is on *why* these changes occur. An understanding of systems and their interacting components will enable students to evaluate supporting theories of earth changes. At the heart of elementary students' initial understanding of the Earth's place in the universe is direct observation of the earth-sun-moon system. Students can derive important conceptual understandings about the system as they describe interactions resulting in shadows, moon phases, and day and night. The use of models and observance of patterns to explain common phenomena is essential to building a conceptual foundation and supporting ideas with evidence at all levels. In middle school, students begin to look beyond what can be directly observed as they explore the earth-sun-moon system, as well as the rest of our solar system, employing the concept of scale within their models. Patterns play an important role as students seek to develop a conceptual understanding of gravity in their world and in the universe. High school is the time to bring all of the ideas together to look at the universe as a whole. Students will use evidence to evaluate and analyze theories related to the origin of the universe and all components of the universe.

High School

Earth/Space Science

SC-HS-2.3.1 Formulate questions and design gravity investigations/experiments. Organize/represent/analyze gravity data. Use evidence to explain phenomena related to gravity. Assess the validity of others' explanations about gravity and associated phenomena.

Gravity is a universal force that each mass exerts on every other mass.

SC-HS-2.3.2 Analyze models of geological time. Make deductions about age based on data. Justify and defend those deductions.

Techniques used to estimate geological time include using radioactive dating, observing rock sequences, and comparing fossils to correlate the rock sequences at various locations.

SC-HS-2.3.3 The forces that hold the nucleus together, at nuclear distances, are usually stronger than the forces that would make it fly apart. Nuclear reactions convert a fraction of the mass of interacting particles into energy, and they can release much greater amounts of energy than atomic interactions. Fission is the splitting of a large nucleus into smaller pieces. Fusion is the joining of two nuclei at extremely high temperature and pressure. Fusion is the process responsible for the energy of the Sun and other stars.

SC-HS-2.3.4 Analyze cause and effect relationships from evidence/data. Predict consequences of both rapid and slow earth processes. Substantiate conclusions about processes or their effects with evidence. Propose solutions to problems caused by the dynamic nature of the Earth's surface. The Earth's surface is dynamic; earthquakes and volcanic eruptions can be observed on a human time scale, but many processes, such as mountain building and plate movements, take place over hundreds of millions of years.
SC-HS-2.3.5 Use visual representations to communicate explanations and relationships between the components of the universe. Analyze/evaluate alternative explanations against current scientific knowledge about the origin of the universe. The big bang theory and observational measurements that support it place the origin of the universe at a time between 10 and 20 billion years ago, when the universe began in a hot dense state. According to this theory, the universe has been expanding since then.
SC-HS-2.3.6 Interpret and analyze graphical representations of data about star life cycles. Make inferences and predictions about stars based on data/evidence. Construct explanations of the origin of planetary material based on evidence. Stars have life cycles of birth through death that are analogous to those of living organisms. During their lifetimes, stars generate energy from nuclear fusion reactions that create successively heavier chemical elements. Some stars explode at the end of their lives, and the heavy elements they have created are blasted out into space to form the next generation of stars and planets.
SC-HS-2.3.7 Early in the history of the universe, the first atoms to form were mainly hydrogen and helium. Over time, these elements clump together by gravitational attraction to form trillions of stars.
SC-HS-2.3.8 Analyze models of crustal plate movement to identify interacting components as well as strengths and limitations. Explain real life phenomena cause by the convection of the Earth's mantle. Infer and/or predict the consequences of this motion on humans and other living things on the planet. The outward transfer of Earth's internal heat drives convection circulation in the mantle. This causes the crustal plates to move on the face of the Earth.
SC-HS-2.3.9 Analyze scale models of the solar system. Compare and contrast solar system components and their formation. The Sun, Earth, and the rest of the solar system formed approximately 4.6 billion years ago from a nebular cloud of dust and gas.

UNITY AND DIVERSITY

All matter is comprised of the same basic elements, goes through the same kinds of energy transformations, and uses the same kinds of forces to move. Living organisms are no exception. Elementary students begin to observe the macroscopic features of organisms in order to make comparisons and classifications based upon likenesses and differences. Looking for patterns in the appearance and behavior of an organism leads to the notion that offspring are much like the parents, but not exactly alike. In middle school, students begin to compare, contrast, and classify the microscopic features of organisms—the cells, as well as investigate reproduction as the essential process to the continuation of all species. Expected patterns of genetic traits are predicted. Distinctions are made between learned behaviors and inherited traits. At the high school level, an in-depth study of the specialization and chemical changes occurring at the cellular level builds upon the foundational ideas developed earlier to investigate DNA and effects of alterations in DNA for an individual organism as well as for a species. Emphasis at every level should be placed upon the understanding that while every living thing is composed of similar small constituents that combine in predictable ways, it is the subtle variations within these small building blocks that account for both the likenesses and differences in form and function that create the diversity of life.

High School

Biological Science

SC-HS-3.4.1 Compare/contrast cell models. Analyze explanations of cell function using current scientific knowledge. Recognize options and propose solutions to real world problems of disease and genetics.

Cells store and use information to guide their functions. The genetic information stored in DNA directs the synthesis of the thousands of proteins that each cell requires.

SC-HS-3.4.2 Most cell functions involve chemical reactions. Food molecules taken into cells react to provide the chemical constituents needed to synthesize other molecules. Both breakdown and synthesis are made possible by a large set of protein catalysts, called enzymes. The breakdown of some of the food molecules enables the cell to store energy in specific chemicals that are used to carry out the many functions of the cell.

SC-HS-3.4.3 Interpret information/data about cell function/regulation. Predict consequences of internal/external environmental change on cell function.

Cell functions are regulated. Regulation occurs both through changes in the activity of the functions performed by proteins and through selective expression of individual genes. This regulation allows cells to respond to their internal and external environments and to control and coordinate cell growth and division.

SC-HS-3.4.4 Plant cells contain chloroplasts, the site of photosynthesis. Plants and many microorganisms (e.g., Euglena) use solar energy to combine molecules of carbon dioxide and water into complex, energy-rich organic compounds and release oxygen to the environment. This process of photosynthesis provides a vital link between the Sun and energy needs of living systems.

SC-HS-3.4.5 Interpret and graphically represent genetic data/information. Make predictions and draw conclusions based on heredity evidence/data. Predict the effects of actions/decisions on offspring. Multicellular organisms, including humans, form from cells that contain two copies of each chromosome. This explains many features of heredity. Transmission of genetic information through sexual reproduction to offspring occurs when male and female gametes that contain only one representative from each chromosome pair unite.
SC-HS-3.4.6 In all organisms and viruses, the instructions for specifying the characteristics are carried in nucleic acids. The chemical and structural properties of nucleic acids determine how the genetic information that underlies heredity is both encoded in genes and replicated.
SC-HS-3.4.7 Formulate questions, design investigations, analyze/interpret data, and choose/defend a conclusion about the behavior of organisms. Behavioral responses to internal changes and external stimuli can be innate or learned. Responses to external stimuli can result from interactions with the organism's own species and/or other species, as well as environmental changes.
SC-HS-3.4.8 Classify organisms into similar groups based on relationships. Compare/contrast organism characteristics. Analyze relationships between organisms. Make inferences about relationships based on internal and external structures and chemical processes. Biological classifications are based on how organisms are related. Organisms are classified into a hierarchy of groups and subgroups based on similarities that reflect their relationships. Species is the most fundamental unit of classification. Different species are classified by the comparison and analysis of their internal and external structures and the similarity of their chemical processes.
SC-HS-3.4.9 Analyze information about the behavior of multicellular organisms. Predict the behavioral consequences of changes at the cellular level. Propose/evaluate solutions to real world problems. Multicellular animals have nervous systems that generate behavior. Nerve cells communicate with each other by secreting specific molecules. Specialized cells in sense organs detect light, sound, and specific chemicals enabling animals to monitor what is going on in the world around them.

BIOLOGICAL CHANGE

The only thing certain is that everything changes. Elementary students build a foundational knowledge of change by observing slow and fast changes caused by nature in their own environment, noting changes that humans and other organisms cause in their environment, and observing fossils found in or near their environment. At the middle school level, students study relationships among populations and ecosystems that contribute to the success or demise of a specific population or species. Students construct basic explanations that can account for the great diversity among organisms. The stage is set for high school students to evaluate the role natural selection plays in the diversity of species. Modern ideas of evolution provide a scientific explanation for three main sets of observable facts about life on earth: the enormous number of different life forms we see about us, the systematic similarities in anatomy and molecular chemistry we see within that diversity, and the sequence of changes in fossils found in successive layers of rock that have been formed over more than a billion years (*Science for All Americans, p. 67)*.

High School

Biological Change

SC-HS-3.5.1 Analyze information/data about atmospheric composition at various times in Earth's history. Make inferences about changes in composition and test explanations against current scientific knowledge about the atmosphere.

Evidence for one-celled forms of life, the bacteria, extends back more than 3.5 billion years. The changes in life over time caused dramatic changes in the composition of the Earth's atmosphere, which did not originally contain oxygen.

SC-HS-3.5.2 Analyze the concept of biological change to extract and identify the supporting components of genetic variability, resource limitations, and reproductive success. Predict consequences of change to any of those components. Propose solutions to real world problem of endangered and extinct species.

Species change over time. Biological change over time is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) natural selection. The consequences of change over time provide a scientific explanation for the fossil record of ancient life forms and for the striking molecular similarities observed among the diverse species of living organisms.

SC-HS-3.5.3 Analyze data for patterns of behavior. Make predictions of the adaptive success of behaviors based on evidence/data. Justify explanations of organism survival based on scientific understandings of behavior.

The broad patterns of behavior exhibited by organisms have changed over time through natural selection to ensure reproductive success. Organisms often live in unpredictable environments, so their behavioral responses must be flexible enough to deal with uncertainty and change. Behaviors often have an adaptive logic.

SC-HS-3.5.4 Analyze/interpret genetic data/information. Model or represent the effects of mutations. Propose solutions to real world genetic problems. Use criteria to evaluate alternative solutions to those problems.

Changes in DNA (mutations) occur spontaneously at low rates. Some of these changes make no difference to the organism, whereas others can change cells and organisms. Only mutations in germ cells have the potential to create the variation that changes an organism's future offspring.

ENERGY TRANSFORMATIONS

Energy transformations are inherent in almost every system in the universe—from tangible examples at the elementary level, such as heat production in simple earth and physical systems to more abstract ideas beginning at middle school, such as those transformations involved in the growth, dying and decay of living systems. The use of models to illustrate the often invisible and abstract notions of energy transfer will aid in conceptualization, especially as students move from the macroscopic level of observation and evidence (primarily elementary school) to the microscopic interactions at the atomic level (middle and high school levels). Students in high school expand their understanding of constancy through the study of a variety of phenomena. Conceptual understanding and application of the laws of thermodynamics connect ideas about matter with energy transformations within all living, physical, and earth systems.

High School

Unifying Change

SC-HS-4.6.1 Analyze data about chemical reactions. Formulate questions and design investigations of chemical reactions. Draw conclusions and justify them using evidence/data from chemical reactions.

Chemical reactions (e.g., acids and bases, redox reactions) occur all around us and in every cell in our bodies. These reactions may release or consume energy.

SC-HS-4.6.2 Analyze information/data on the flow of matter and energy through a system. Create representations to communicate understanding of the relationships and connections between matter, energy, living systems, and the physical environment.

As matter and energy flow through different organizational levels (e.g., cells, organs, organisms, communities) and between living systems and the physical environment, chemical elements are recombined in different ways. Each recombination results in storage and dissipation of energy into the environment as heat. Matter and energy are conserved in each change.

SC-HS-4.6.3 Formulate questions about waves and design investigations to answer those questions. Analyze wave information/data. Make predictions and inferences about wave behavior and energy transfer. Apply knowledge of waves to real life phenomena.

Waves, including sound and seismic waves, waves on water, and electromagnetic waves, can transfer energy when they interact with matter. Apparent changes in frequency can provide information about relative motion.

SC-HS-4.6.4 Electromagnetic waves, including radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, x-rays, and gamma rays, result when a charged object is accelerated.

SC-HS-4.6.5 Use data to explain consequences of energy change/transfer. Evaluate explanations of phenomena using current scientific knowledge about energy.

The total energy of the universe is constant. Energy can change forms and/or be transferred in many ways, but it can neither be created nor destroyed.

SC-HS-4.6.6 Heat is the manifestation of the random motion and vibrations of atoms

SC-HS-4.6.7 Use information/data to explain real world applications of energy. Evaluate explanations of mechanical systems using current scientific knowledge about energy.

The universe becomes less orderly and less organized over time. Thus, the overall effect is that the energy is spread out uniformly. For example, in the operation of mechanical systems, the useful energy output is always less than the energy input; the difference appears as heat.

SC-HS-4.6.8 Explain limitations/usefulness of models used to represent Earth's energy sources. Predict the consequences of changes to any component of the Earth system. Describe the connections between the functioning of the Earth system and its sources of energy.

Earth systems have sources of energy that are internal and external to the Earth. The Sun is the major external source of energy. Two primary sources of internal energy are the decay of radioactive isotopes and the gravitational energy from Earth's original formation.

SC-HS-4.6.9 Interpret climate data to determine cause and effect relationships, construct inferences, and make predictions.

Global climate is determined by energy transfer from the Sun at and near Earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the Earth's rotation and static conditions such as the position of mountain ranges and oceans.

SC-HS-4.6.10 Analyze information and use/create models to explain the movement of matter and energy in biogeochemical cycles and related phenomena. Evaluate the effectiveness/accuracy of models/representations. Predict and analyze the consequences of changes in reservoirs.

Movement of matter between reservoirs is driven by Earth's internal and external sources of energy. These movements are often accompanied by a change in physical and chemical properties of the matter. Carbon, for example, occurs in carbonate rocks such as limestone, in the atmosphere as carbon dioxide gas, in water as dissolved carbon dioxide, and in all organisms as complex molecules that control the chemistry of life.

SC-HS-4.6.11 Synthesize prior knowledge of energy in living systems and apply to new concepts in order to explain phenomena.

Living systems require a continuous input of energy to maintain their chemical and physical organization since the universal tendency is toward more disorganized states. The energy for life primarily derives from the Sun. Plants capture energy by absorbing light and using it to form strong (covalent) chemical bonds between the atoms of carbon-containing molecules. These molecules can be used to assemble larger molecules (e.g., DNA, proteins, sugars, fats). In addition, the energy stored in the bonds between the atoms can be used as sources of energy for life processes.

SC-HS-4.6.12 Analyze the concept of energy from food molecules to extract and identify supporting components and mechanisms. Recognize real world applications and make connections to health issues.

The chemical bonds of food molecules contain energy. Energy is released when the bonds of food molecules are broken and new compounds with lower energy bonds are formed. Cells usually store this energy temporarily in the phosphate bonds of ATP. During the process of cellular respiration, some energy is lost as heat.

INTERDEPENDENCE

It is not difficult for students to grasp the general notion that species depend on one another and on the environment for survival. But their awareness must be supported by knowledge of the kinds of relationships that exist among organisms, the kinds of physical conditions that organisms must cope with, the kinds of environments created by the interaction of organisms with one another and their physical surroundings, and the complexity of such systems. Elementary learners need to become acquainted with ecosystems that are easily observable to them by beginning to study the habitats of many types of local organisms. Students begin to investigate the survival needs of different organisms and how the environment affects optimum conditions for survival. In middle school, students should be guided from specific examples of the interdependency of organisms to a more systematic view of the interactions that take place among organisms and their surroundings. At the high school level, the concept of an ecosystem should bring coherence to the complex array of relationships among organisms and environments that students have encountered. Students growing understanding of systems in general will reinforce the concept of ecosystems. Stability and change in ecosystems can be considered in terms of variables such as population size, number and kinds of species, productivity, and the effect of human intervention. (*adapted from Benchmarks for Science Literacy)*

High School

SC-HS-4.7.1 Analyze relationships among organisms in ecosystems and describe their interactions. Predict the effects on other organisms of changes to one or more components of the ecosystem.

Organisms both cooperate and compete in ecosystems. Often changes in one component of an ecosystem will have effects on the entire system that are difficult to predict. The interrelationships and interdependencies of these organisms may generate ecosystems that are stable for hundreds or thousands of years.

SC-HS-4.7.2 Describe the interactions of humans with other organisms. Provide/evaluate proposed solutions to environmental problems from multiple perspectives. Justify positions using evidence/data. Establish and apply evaluative criteria for testing alternative solutions to global problems caused by humans.

Human beings live within the world's ecosystems. Human activities can deliberately or inadvertently alter the dynamics in ecosystems. These activities can threaten current and future global stability and, if not addressed, ecosystems can be irreversibly affected.

SC-HS-4.7.3 Analyze cause and effect relationships between the components of the Earth system. Predict the consequences of changes to any component. Substantiate conclusions with evidence/data and propose solutions to global problems.

Interactions among the solid Earth, the oceans, the atmosphere, and living things have resulted in the ongoing development of a changing Earth system.

SC-HS-4.7.4 Analyze information/data about biochemical cycles. Evaluate the effectiveness/ accuracy of models/representations of cyclical phenomena. Predict and analyze the consequences of changes at any stage in the cycle. Propose and justify solutions to real life problems caused by changes in any component. Atoms (e.g., carbon) and molecules (e.g., water, nitrogen, carbon dioxide, and oxygen) cycle among the living and nonliving components of the biosphere.
SC-HS-4.7.5 Create and analyze mathematical/physical/conceptual models of populations. Use evidence/data to predict the consequences to a population of changes in resources. Propose and justify solutions to real world problems of population control. Living organisms have the capacity to produce populations of infinite size. However, behaviors, environments, and resources influence the size of populations. Models (e.g., mathematical, physical, conceptual) can be used to make predictions about changes in the size or rate of growth of a population.